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Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
PHYSICS


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ABSTRACT

A pneumatic mosaic infrared detector is proposed which would have the necessary sensitivity, simplicity and ruggedness for field use by combat troops. A laboratory model of the pneumatic mosaic infrared detector has been developed. The major items included were the development of procedures for producing the 447 unit cell mosaic and the development of procedures for producing gelatin films of thickness between 1,000 $A^{o}$ and 5,000 $A^{o}$ and diameter of two inches. The response of the unit pneumatic cell was investigated and the results were as predicted by theory; i.e., the response increased with decreasing length to radius ratio. The predicted optimum of response at $l/r = 1.2$ could not be checked with the apparatus used. Mechanical difficulties prevented the final testing of the model in time for inclusion of data on the responsiveness and sensitivity.

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| | |
|---|---|
| $W$ | Mechanical Energy Generated in the Gas Cell |
| $T_o$ | Ambient Temperature |
| $u$ | Radiation Absorbed by Cell Per Unit Time |
| $q$ | Heat Energy Absorbed by Cell |
| $c$ | Heat Capacity |
| $\sigma$ | Stefan - Boltzman Constant |
| $A$ | Area of Blackened Detector |
| $T_1$ | Temperature of Distant Source |
| $T_2$ | Temperature of Black Body Receiving Radiation |
| $T$ | Average Temperature of the Two Bodies |
| $f$ | Ratio of Focal Length to Aperature |
| $A'$ | Aperature Area |
| $\mathcal{E}$ | Efficiency of Heat Cell |
| $\tau$ | Time Constant of Heat Cell |
| $\Delta T_1$ | Temperature Difference Between Source and Background |
| $\Delta T_2$ | Temperature Change in Cell |
| $\Delta P$ | Pressure Change in Cell |
| $P_1$ | Ambient Pressure in Cell |
| $R$ | Radius of Curvature |
| $T_s$ | Surface Tension |
| $Z$ | Inverse Coefficient of Curvature |
| $C$ | Temperature Contrast of Target |
| $\mathcal{J}$ | Periodic Change in Average Gas Temperature |
| $\omega$ | Circular Chopping Frequency |
| $G_c$ | Heat Conductivity of the Cell |

| | |
|---|---|
| $Q$ | Amplitude of Periodic Change in Thermal Power Dissipated in Cell |
| $K$ | Heat Conductance of a Gas |
| $G_r$ | Radiation Conductance of Cell |
| $k'$ | Specific Heat Conductivity |
| $V$ | Volume of Cell |
| $k_1$ | Constant Which Reduces Geometrical Volume to Effective Volume |
| $c_r$ | Specific Heat Capacity |
| $l$ | Cell Length |
| $r$ | Cell Radius |
| $\eta$ | Radiation Absorption Efficiency |
| $k$ | Boltzman's Constant |
| $R'$ | Thermal Resistance |
| $\Delta f$ | Bandwidth of Output Device |
| $h$ | Film Displacement at Centerline |

## 1. Introduction

Infrared is electromagnetic radiation the spectral range of which extends from the visible light to the radio region, or in wavelength from one micron to one millimeter. Infrared radiation is caused by molecular vibration and rotation, by crystalline fields in solids or by cooperation between molecules in liquids and solids.

In the last few years the field of infrared radiation and its application has been expanding very rapidly. Infrared systems have been developed for uses such as pyrometers, spectrometers, continuous process analyzers, and search and tracking systems. The heart of any infrared system is the detector. The most commonly used detectors may be divided by their mechanism of response into two broad classes: (1) Thermal receivers and (2) solid state electronic devices. Included within the solid state devices are: Germanium detectors, photoconductive cells of the lead salts, and indium antimonide detectors. Under the thermal receivers are included: Bolometers, thermopiles and pneumatic detectors. /1/

In its simplest form, the pneumatic type detector consists of a small gas filled chamber equipped with an infrared transmitting window, some means for absorbing the radiation admitted to the chamber, and finally some method for transposing pressure change in the chamber into measureable signal output, usually electrical or optical. One of the earliest devices of this type was described by Hayes where a carbonized vegetable "fluff" material was sealed in a chamber to absorb the radiation. /2/ One end of the radiation chamber was closed with a transmitting

window and the other with a one mil duraluminum diaphragm which formed one plate of a condenser. As the diaphragm expanded due to pressure changes in the tube, capacitance changes across the condenser provided a direct means for measuring the radiation input into the cell.

Though the output of the Hayes type cell was extremely small, the pneumatic infrared detector was investigated for military purposes during World War II. The possibility of utilizing a number of cells to detect infrared radiation was investigated. An experimental unit of 150 1/8 inch honey combed cells formed by partially boring a brass block was fabricated. The cells were filled with carbonized vegetable fluff and one end sealed with an infrared window. The other side of the block was machined and polished flat. A thin circular collodian film was placed within a thousandth of an inch of this flat surface. On the other side of the collodian film and almost parallel to it was placed the inner face of an optical wedge. When a flow of air in or out of the cells was caused by their momentary exposure to the infrared image of an object having a temperature differential from its background, an interference pattern was produced between the collodian film and the inner surface of the glass wedge. In order to obtain a good degree of sensitivity the collodian film had to be placed so close to the brass block that an intake of air into the cells caused the collodian film to be sucked in against the brass block and adhere to it. Therefore, this unit did not have sufficient sensitivity when made rugged enough for military purposes or enough ruggedness when it had enough sensitivity. /3/

Although ineffective for military use the basic principle was used in the development of a unit cell by Golay and Zahl, primarily for

laboratory use. A thin blackened film was substituted for the carbonized fluff as the radiation receiver. Detection of thermal changes was accomplished by the observation of Newton's rings which were formed between the collodian film and the optical wedge when the film was expanded. /3/

A later development of this unit cell was made by Golay which incorporated a photoelectric cell in lieu of the optical observation system and put the photoelectric output through an amplifier to indicate the response to infrared input. Upon the use of the photoelectric cell the glass wedge was eliminated, and a line grid between the lamp and the collodian film was substituted. /4/

Another type pneumatic detector is the Patterson-Moos cell. In this type detector the gas within the cell cavity absorbs radiation which results in a pressure and temperature increase within the chamber. By filling the cavities with gases having selective absorption bands, an individual can achieve absorption in only preselected wave length intervals, since the detector will respond only to wave lengths at which the gas absorbs. The detection is similar to that of the Hayes cell, where capacitive or condenser type output serves to extract electrical signals. /5/

Attempts have been made to employ a number of detectors, each of equal and very small sensitive surface area, arranged in the form of a pattern or mosaic. This in effect gives a picture of an object which is at a temperature differential from its background. One such mosaic detector consisting of 100 elements has been developed using the bolometer principle. Each element may be connected to its own amplifier,

or a scanning system similar to that employed in television could be used to scan each individual element in sequence. /6/

The work performed for this project was developmental research on several of the basic components of an imaging infrared detector to consist of a mosaic of pneumatic thermal detectors. Each detecting cell works individually. The radiation enters the cell through an infrared transmitting window and is absorbed by a carbon black coating on the side walls of the cell. This causes an increase in pressure within the cell. The increase in pressure expands a thin membrane at the other end of the cell. A schlieren system is used to observe the distortion of the membrane, providing an increase in intensity of light with increasing distortion. When a large number of such cells are combined, a picture of the infrared emitting surface would be provided. Such a detecting system has no requirements for electronic components, is a non-selective system, and can be made compact and rugged. Such an infrared detector, which would present a visual image of the thermal radiation from an extended area, could be used to advantage in military applications. Battlefield surveillance, reconnaisance, and tracking systems are possible uses by ground troops. Aircraft or even missile reconnaisance, mapping, or guidance are also military possibilities. The plastics, petroleum, and steel industries should also be able to profitably use such a mosaic detector.

## 2. Theoretical discussion

The pneumatic cell is a heat engine that converts thermal energy into mechanical energy. If $W$ is the mechanical energy generated in the pneumatic cell, then the mechanical energy from the heat engine operating between the temperatures of $T_2$ and $T_0$ is limited by

$$(1) \qquad \int_0^{2t} dW \leqq \int_0^{t} \frac{T_2 - T_0}{T_2}\, u\, dt$$

Where the lefthand integral is for time $2t$ to include energy during the cooling off period and $u$ is the radiation absorbed for $t$ seconds. /7/

The resulting rise in temperature, $(T_2 - T_0)$, from the heat energy $q = ut$ depends upon the heat capacity $c$, the heat lost by conduction, and the heat lost by radiation, or

$$(2) \qquad q = \int_0^{t} c\, dt + \int_0^{t} c(T_2 - T_0)\, dt + \int_0^{t} 4\sigma A T^3 (T_2 - T_0)\, dt$$

where $\sigma$ is the Stefan-Boltzmann constant and $A$ is the area of the blackened detector. In practice, the conduction losses are much greater than the radiation losses and the last two integrals on the right can be combined with a single constant $K \approx C + 4\sigma A T^3$ . /7/

Since $u$ is the rate at which energy is received and $u = \frac{dq}{dt}$ , equation (2) can be approximated as follows:

$$(3) \qquad \frac{A'\sigma T^3 (T_1 - T_2)}{f^2} = k(T_2 - T_0) + c\frac{dT_2}{dt}$$

The term on the left is the approximate rate at which energy is received by a black body at temperature $T_2$ from a distant extended source at temperature $T_1$ The radiation is focused on an aperture of area $A'$

by a mirror whose ratio of focal length to aperture is $f$. $T$ is the average temperature of the two bodies.

The first term of the right side is the combined rate at which energy is lost by radiation and conduction from the cell to its surroundings which are at ambient temperature $T_o$. The second term represents the rate at which energy is absorbed to raise the temperature of the cell and $c$ is the heat capacity of the cell. Letting

$$B = \frac{A'\sigma T^3}{f^2}$$

and rewriting,

(4) $$c\frac{dT_2}{dt} + (B+K)T_2 - (KT_o + BT_1) = 0$$

Equation (4) has the following solution:

(5) $$T_2 = \frac{BT_1 + KT_o}{B+K}\left(1 - e^{-\frac{B+K}{c}t}\right) + T_o\, e^{-\frac{B+K}{c}t}$$

Adding and subtracting $BT_o$ from the coefficient of the first term and rewriting,

(6) $$T_2 = \frac{B}{B+K}(T_1 - T_o)\left(1 - e^{-\frac{B+K}{c}t}\right) + T_o$$

Thus, the cell temperature will change by an amount proportional to the difference in temperature between the distant source and the surroundings. The efficiency, $\mathcal{E}$, of the heat cell is given by

(7) $$\mathcal{E} = \frac{B}{B+K}$$

and the time constant, $\tau$, is given by

(8) $$\tau = \frac{c}{B+K}$$

Rewriting equation (6) into a more useful form

(9) $$\Delta T_2 = \varepsilon \Delta T_1 (1 - e^{-t/\tau})$$

where

$$\Delta T_2 = T_2 - T_0$$

$$\Delta T_1 = T_1 - T_0$$

The accompanying change in pressure for this change in temperature would be

(10) $$\Delta P = P_0 \frac{\Delta T_2}{T_0}$$

and radius of curvature of the mirror film is given by

(11) $$R = \frac{4 T_s}{\Delta P}$$

where $T_s$ is the surface tension of the film.

Combining (9), (10), and (11) and solving for $\frac{1}{R}$,

(12) $$\frac{1}{R} = \frac{P_0 \varepsilon}{4 T_s} \frac{\Delta T_1}{T_0} (1 - e^{-t/\tau})$$

On the right side, the term $\frac{P_0}{4 T_s}$ is seen from equation (11) to have the units of $cm^{-1}$. Then an inverse coefficient of curvature, Z, can be defined as

$$Z = \frac{P_0}{4 T_s}$$

From the standard definition of contrast, the temperature contrast of the target is given by

$$C' = \frac{\Delta T_1}{T_0}$$

Equation (12) then becomes

$$\frac{1}{R} = Z \mathcal{E} C'(1 - e^{-t/\tau}) \tag{13}$$

Thus, the response is given by a coefficient, which is dependent upon the ambient cell pressure and the surface tension of the film, the efficiency of the cell, and the contrast of the target with its background. The last term is the time response.

Let Q be the amplitude of the periodic change in the thermal power dissipated in the cell which causes the variation in the average gas temperature. Then, the amplitude of the periodic change in the average gas temperature is given by

$$\mathcal{S} = \frac{Q}{|G_c + i\omega c|} \tag{14}$$

where c is the heat capacity of the cell, $\omega$ is the circular chopping frequency, and $G_c$ is the heat conductivity of the cell. /8/ The denominator is the magnitude of the thermal impedance. Rewriting (14)

$$\mathcal{S} = \frac{Q}{G_c} \frac{1}{|1 + i\omega \frac{c}{G_c}|} \tag{15}$$

The first term on the right side of (15) defines the static or dc average temperature change and the time - dependent term defines the frequency response. Defining time constant $\tau$ by $\omega\tau = 1$, the time constant is given by

$$\tau = \frac{c}{G_c} \tag{16}$$

The cell is connected to a source of radiation to be detected through a radiation conductance, $G_r$. A portion of the received

radiation is shunted to the surroundings by the thermal conduction, thus the efficiency of energy conversion is given by

(17) $$\mathcal{E} = \frac{G_r}{G_r + G_c} \approx \frac{G_r}{G_c}$$

which is in accordance with equation (7). For all cells considered here the terms c, $G_c$, and $G_r$ are functions of cell geometry. /9/

In order to determine to a first approximation the geometric functions of $\mathcal{E}$ and $\tau$, the following assumptions are made:

1. Cell dimensions are small compared to the depth of penetration of temperature fluctuations, thus, heat is emitted with equal density over the total gas volume.

2. For finite shapes, the heat conduction equals the sum of heat conductions corresponding to orthogonal coordinates.

3. The carbon black deposit on the sidewalls is relatively thick and loosely packed, and the radiation will be absorbed on the inner surface of the carbon; therefore, the heat conducted from the cell may be neglected compared to the heat conduction by the gas.

Then the heat conductance, $G_c$, may be computed from the expression

(18) $$G_c = \frac{n(2+n)vK}{a^2}$$

where K is the heat conductance of the gas and v is the cell volume. The values of n are 1, 2, and 3 for an infinite plate, an infinite cylinder, and a sphere, respectively, and a equals one-half the thickness of the plate, the radius of the cylinder, and the radius of the sphere, respectively. /8/

For a cylindrical cell of radius r and length l, the thermal

capacity is given by

(19) $$c = k_1 \pi c_r r^2 \ell$$

where $c_r$ is the specific heat capacity (ergs cm$^{-3}$ $^oC^{-1}$) and $k_1$ is a constant which reduces the geometrical volume to an effective volume. This constant increases with $\ell/r$ ratios increasing from approximately 0.64 at $\ell/r = 2$ to approximately 0.85.

The thermal conductivity for a cylindrical non-selective optic-acoustic radiation receiver is given from (18) as

(20) $$G_c = 8\pi k'\ell + \frac{8\pi k' r^2}{\ell}$$

(21) $$= 8\pi k' \ell \left[1 + (r/\ell)^2\right]$$

where $k'$ is the specific heat conductivity (erg cm$^{-1}$ sec$^{-1}$ $^oC^{-1}$). /8/

Substituting (19) and (21) into (16),

(22) $$\tau = \frac{c_r r^2}{8k'} \frac{k_1}{\left[1 + (r/\ell)^2\right]}$$

Thus, the time constant varies as the square of the radius for constant $\ell/r$ ratios, and for any value of radius the time constant decreases with decreasing $\ell/r$ ratios. /10/

The radiation conductance is dependent on the receiving area of the cell and can be estimated from the expression

(23) $$G_r = 2\eta k^2 \pi r \ell \frac{d(\sigma T^4)}{dt}$$

where $\eta$ is the radiation absorption efficiency and k is Boltzmann's constant.

For $T = 300^\circ$ K, $\eta = 2/3$, and $k = 0.9$,

(24) $$G_r = 6.6 \times 10^3 \, \pi r l$$

Substituting (21) and (24) into (17),

(25) $$\mathcal{E} = 8.2 \times 10^2 \frac{r}{k'} \frac{1}{[1 + (r/l)^2]}$$

However, (21) has a minimum when $l = 1.2r$ and the efficiency will be a maximum at this point. Then

(26) $$\mathcal{E}_{max} = 3.90 \times 10^2 \frac{r}{k'}$$

and

(27) $$\tau = 0.07 \frac{c_r}{k'} r^2$$

/10/

The mean square fluctuation of the gas temperature is given by

(28) $$\overline{\mathcal{T}}^2 = 4k T^2 R_1 \Delta f$$

where $k$ is Boltzmann's constant, $R_1$ the thermal resistance, and $\Delta f$ the bandwidth of the output device. The thermal resistance is given from (14) and (16) as

(29) $$R_1 = \frac{1}{G_0 [1 + (\omega \tau)^2]}$$

Thus,

(30) $$\overline{\mathcal{T}}^2 = \frac{4k T^2 \Delta f}{G_0 [1 + (\omega \tau)^2]}$$

Combining (14) and (30) gives

(31) $$Q = \left[4kT^2 G_c \Delta f\right]^{1/2}$$

For film absorbing cells the thermal conductance has been shown to be a minimum when $l = 1.2r$, and substituting this in (21) and the result into (31) gives the expression for minimum noise equivalent input power for pneumatic cells.

(32) $$Q = \left[4kT^2 (16.2\,\pi k' r)\Delta f\right]^{1/2}$$ /8/

In terms of unit bandwidth (31) becomes

(33) $$Q = \left[203\, k T^2 k' r\right]^{1/2}$$

This expression shows that NEP (watts sec$^{\frac{1}{2}}$) varies as the square root of radius.

Combining (13), (26), and (27) gives a complete expression for $\frac{1}{R}$.

(34) $$\frac{1}{R} = \frac{P_o}{4T_s}\left(390\frac{r}{k'}\right)\frac{\Delta T_1}{T_o}\left(1 - e^{-\frac{k'}{0.07 C_r r^2}t}\right)$$

and for $T_1 = 300^\circ K$

(35) $$\frac{1}{R} = 0.33\,\frac{P_o}{T_s}\,\frac{r}{k'}\,\Delta T_1\left(1 - e^{-\frac{14.3k'}{C_r r^2}t}\right)$$

From the geometry $h$, the deflection of the mirror film on the cell axis, is given by

$$h = \frac{r^2}{2R}$$

and

(36) $$h = 0.16 \frac{P_o}{T_s} \frac{r^3}{k'} \Delta T_1 \left(1 - e^{-\frac{14.3 k'}{c_r r^2} t}\right)$$

In one time constant the displacement is

(37) $$h = 0.101 \frac{P_o}{T_s} \frac{r^3}{k'} \Delta T_1$$

Changing units of r to microns and h to Angstroms and expressing pressure as a ratio n of actual pressure to one atmosphere, $10^6$ dynes/cm$^2$

(38) $$h = 10.1 \frac{n r^3}{T_s k'} \Delta T_1$$

Assuming a 5000 A$^o$ source for the output optics, the displacement h in wavelengths is given by

(39) $$h_\lambda = 2.02 \times 10^{-3} \frac{n r^3}{T_s k'} \Delta T_1$$

Rewriting in terms of $\Delta T_1$

(40) $$\Delta T_1 = \frac{T_s k'}{2.02 n r^3} 10^3 h_\lambda$$

Thus, it is possible to compute the minimum detectable temperature difference in terms of cell parameters and the minimum detectable deflection by the output optics.

3. General description

The pneumatic infrared mosaic detector system is composed of six basic elements: The chopper system, the optical system, the thermal window, the cell mosaic, the flexible mirrored film, and the schlieren viewing system.

The chopper system - is required to prevent thermal drift and to reduce background interference. The chopper planned for the laboratory system is a standard chopper system revolving at approximately ten cycles per second and powered by a small electric motor.

The optical system - is required to collect the infrared radiation and focus it into the cell mosaic.

The thermal window - forms the forward seal on the cell mosaic and allows the infrared radiation to pass from the atmosphere into the cells.

The cell mosaic - Individual cells absorb radiation, increasing the temperature and pressure of the gas within the cell.

The flexible mirrored film - responds to an increase in pressure within the cells of the cell mosaic.

The schlieren viewing system - detects the changes in the flexible mirrored film thereby providing a visual image of the radiating object.

4. The optical system

The optical system was taken from a type C3 telescope which was used with Navy Nancy equipment during World War II. The collecting mirror is a spherical mirror with outside diameter of 8.85 cm. and a circular aperture of 4.70 cm. diameter. A plane mirror of 5.00 cm. diameter is used in conjunction with the above mirror. The focal length of the lens system is 6.04 cm., with an effective aperture of F/0.9 and angular field of 25$^{\circ}$ and has an optical efficiency factor of approximately 25%. The optical system was manufactured by Polaroid Corporation of Cambridge, Mass. See Figure 1.

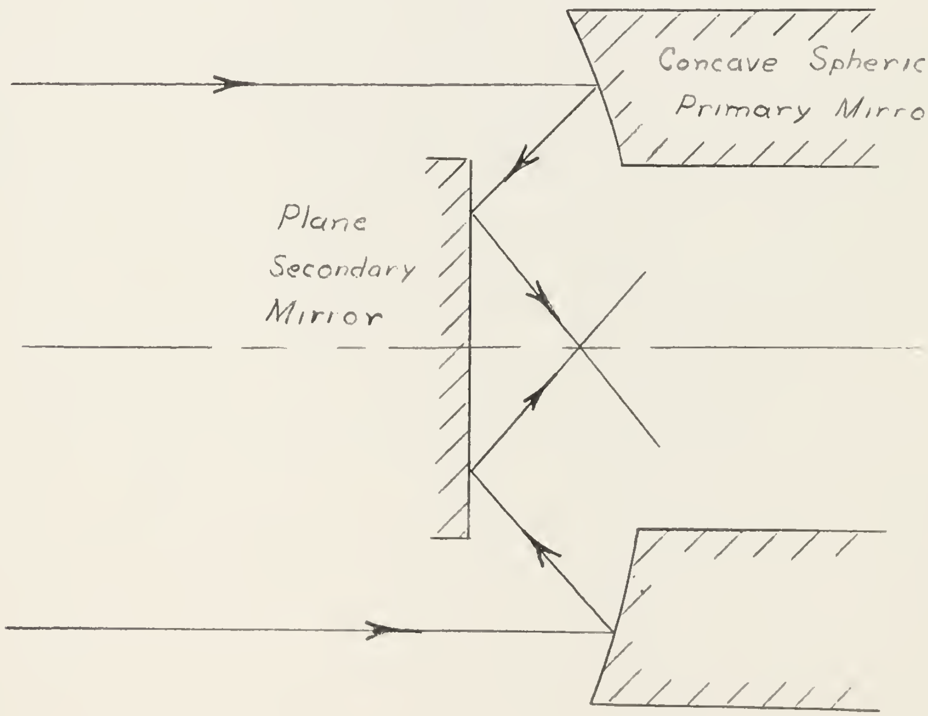


Figure 1 Optical System

5. The thermal window

The thermal window serves two purposes: It seals the front end of the cells of the mosaic and transmits the radiation into the cells. The material chosen for this purpose was IRTRAN-2 manufactured by the Eastman Kodak Company. The window is one and one-half inches in diameter and is one eighth inch thick. For this thickness the IRTRAN-2 has a transmittance of over 60 percent for the important region of wavelengths from two microns to 12.5 microns. The strength of this material also helps reduce the possibility of warping of the optically flat surface of the cell mosaic.

6. The cell mosaic

The item of primary importance to the design of the mosaic detector is the cell mosaic. The criteria desired was: (1) that there be a large number of cells placed very close together in order to provide an acceptable visual image, (2) the cells be well insulated from each other in order that heat not be conducted from one cell to another, (3) the cells be fabricated of a material capable of being ground and polished to an optically flat surface, and (4) that the mosaic be of sufficient strength so when cut to a length of approximately 1/8 inch it would not warp from the optically flat requirement.

It was decided to investigate three possibilities: (1) To drill holes in a plastic, (2) to drill holes in a metal, and (3) to glue glass capillary tubes together.

Plastic, being a thermal insulator, was very difficult to drill. The drilling of small holes heated up the drill so that one drill could be used for only one or two holes, or the holes would not be uniform. Being somewhat soft, especially after the drilling operation, it was considered that it would be difficult to obtain an optically flat surface. Another disadvantage of the plastic is its high thermal coefficient of expansion. If the holes were drilled close enough together to satisfy requirement (1) above, the plastic also would not have sufficient strength to hold the optically flat surface. The metal was initially disregarded due to its heat conduction characteristics. Because of the above, it was decided to pursue the use of capillary glass tubing as the most feasible method.

The choice of the size of capillary tubing to be used was based on the following considerations: (1) As small a tube as possible would provide for the greatest resolution of the image, (2) the maximum theoretical efficiency is obtained with a ratio of length to radius of 1.2, (3) the diameter of the Golay cell is 1/8 inch, (4) the minimum practical limit of length was considered to be 1/8 inch, (5) capillary tubing had to be uniform and therefore available to close specifications. In view of the above considerations a compromise of a capillary tube with an inside diameter of one millimeter was selected. The tubing utilized had a wall thickness of .25 mm and thus a 1.5 mm outside diameter.

In order to obtain the closest packing, to minimize any lost space between the tubes, and to obtain an ordered array, a hexagonal shape was necessary. During initial experimentation and grinding on an experimental hexagonal bundle of 61 capillary tubes, it was determined that some outside support was required because without such support the exterior tubes chipped and broke during the cutting and grinding operations. It was decided to use a glass tube as the exterior support because in the grinding and polishing operations it would most closely resemble the glass capillary tubes and would probably grind more uniformly. In order to fit within the 47mm aperture of the optical system, a 41 mm glass tube was used as an outside support. A hexagon utilizing 397 capillary tubes could be fitted into this exterior glass support.

Various glues and epoxy resins were investigated. It was considered

that Armstrong C7 epoxy using activator "H" which has a three hour cure time at 100° C, a pot life of approximately 45 minutes, good potting characteristics, and hardness and strength after curing was the most desirable.

The capillary tubes were broken to six inch lengths, and were sealed at each end by the use of a bunsen burner flame. The sealing was necessary to prevent epoxy resin from entering the capillary tubes during the gluing and curing operation, and it was also found convenient to handle the tubes with the ends somewhat rounded and smooth. The epoxy resin was applied to the tubes hot by heating the resin in a shallow pan and placing the tubes therein. They were then placed carefully in precut hexagon holders made to the exact dimensions necessary to hold 397 tubes snugly. It was found that several times during the operation the hexagons had to be placed in the oven and heated in order to obtain the close packing necessary. This heating gave the epoxy resin a very low vicosity which was needed to squeeze out any excess. A tube count was carefully maintained to insure that if a tube was broken it was replaced and the operation was completed with 397 tubes in the hexagon bundle. Near the end of the operation the epoxy obscured any spaces in the array and the count was the only means to insure that no blank spaces would exist in the finished product. After the tubes were placed in the hexagon, the tube bundle was heated and placed in a vacuum in order to draw out as many entrapped air bubbles as possible. The means by which the hexagonal holders were secured and the means by which the capillary tubes were placed therein is shown in Figure 2.

After the epoxy was properly cured, one of the hexagon guides was removed as shown in Figure 3. The hexagon mosaic was placed within the exterior glass tube, and plaster of paris was applied around the base of the tube to seal it so that epoxy resin would not drain out during further curing operations. The space between the hexagon and the exterior glass tube was then completely filled with hot epoxy resin and additional tubes were slid into this area. See Figure 4.

It was found that the difference in thermal expansion between the exterior glass tube and the epoxy resin caused problems in the use of a glass tube for exterior support. The glass tube broke during subsequent heating operations. Therefore, it was decided to use a brass tube of approximately the same dimensions for exterior support.

After the tube matrix was cured the ends were cut off by means of a thin carborundum wheel. Pure resin heated to a temperature of $130^{\circ}$ C was pulled into the tubes as far as possible by using a vacuum. It was found that such support was required in order to prevent chipping and cracking of the interior of the capillary tube surfaces during the cutting, grinding, and polishing operations. The use of pure resin as a filling agent was considered the most desirable after testing various fillers and solvents. See Figure 5.

One fourth inch slices were cut from the tube bundle to form the cell mosaic. After attempting various methods of grinding, a grinding cylinder was employed on a flat glass plate using a fine abrasive. This cylinder is shown in Figure 6. The thin slices were ground to a thickness of approximately 1/8 inch, and the sides made parallel. The final

polishing and grinding operation was done commercially by Tinsley Laboratories in Berkeley, California.

Prior to the final polishing operation, an IRTRAN-2 window was glued to one of the two cell mosaics which were prepared. This was done to forestall the possibility of warping the mosaic should this gluing operation be done after the final grinding and polishing. It was not intended to glue the IRTRAN-2 to the second mosaic in case it were found necessary to allow for bleeding at the front surface. In order to accomplish the gluing, a thin layer of turpentine was applied to one side of the cell mosaic and after approximately one hour, enough resin had been dissolved to insure that a coat of glue would not cover the entire IRTRAN-2 window. After experimenting with approximately ten different methods of applying Eastman 910 glue to the cell mosaic, it was found that a thin piece of rubber stretched over a hard surface could be coated evenly with two drops of glue, the cell mosaic pressed to this surface and then fitted to the IRTRAN-2 window. Later inspection of the window indicated that a minimum of glue was present around the edges of the capillary tubes.

After final grinding and polishing of the mosaic, the resin was extracted from the capillary tubes by placing turpentine in a watch cleaning machine and putting the cell mosaic in the machine for several days while periodically: (1) Placing a vacuum on the cell with a soft rubber hose, (2) jetting it with a stream of air, and (3) using wood splinters the approximate size of the capillary holes to loosen the resin.

The final operation with the cell mosaic was the insertion of the carbon black required to absorb the infrared radiation. It was considered that the most uniform response would be obtained if only the sides of the capillary tubes were coated with the carbon black. In order to accomplish this operation, wood splinters were cut to the approximate diameter of the capillary tubes and butyrate dope was placed on the side of the splinter and transferred to the interior surfaces of the capillary tube. Carbon black was immediately placed in the capillary tube and after all tubes were filled, the cell mosaic was shaken so that the interior surfaces only remained coated with carbon black.

A method of providing for bleeding of the cells will be required to accommodate the gradual changes in ambient pressure or temperature unless a constant temperature, constant pressure chamber is provided to surround the instrument. This bleeding might be provided through the porosity of the flexible mirrored film (the method planned to try on the glued IRTRAN-2 window). The bleeding also might be provided through a roughened surface between the IRTRAN-2 and the cell mosaic (the method planned to try on the second cell mosaic which does not have the IRTRAN-2 glued to it). This area in particular will require further study.

7. The flexible mirrored film

The next major area in the experimental development of the mosaic detector was the fabrication of a thin film. The criteria for this film was as follows: (1) The thickness of the film to be as small as possible with a goal of 300 Angstroms and not over 10,000 Angstroms, (2) the film be flexible so that small changes in pressure behind the film bulge it sufficiently to be detected and that the film return to its original flat position after the pressure is removed, (3) the film have sufficient strength so that it will withstand repeated expansions and contractions without breaking or cracking, and (4) the overall size of the film be at least one and one half inches diameter so that it can be mounted over the cell mosaic.

The first attempts to produce a film to meet the above criteria were to float films on water. Three types of films were tried: (1) Collodian dissolved in ether, (2) cellulose acetate dissolved in methyl acetate, and (3) butyrate dope. Experiments were performed using varying concentrations, varying amounts, varying temperature of water, varying height of the applicator above the water surface, and the use of caster oil and other spreading agents on the surface of the water. The results of these experiments were disappointing.

Through the suggestion of Dr. Max L. Panzer, films made of gelatin floated on mercury were attempted. There were four essential conditions in the floating of successful films: (1) The mercury container had to be mounted on a vibration free surface so that no waves were produced on the mercury surface, (2) absolute cleanliness of the mercury and

equipment was essential so that no inpurities were introduced into the film, (3) an essentially dust free area or atmosphere was required so that no dirt, lint, etc. would adhere to the film surface, and (4) the curing of the film in a formalin atmosphere to properly preserve the protein gelatin was required.

In addition to these essential conditions it was found that there were a number of variables which affected the quality of film obtained: (1) The percent of gelatin to water solution, (2) the amount of ethanol added to the solution as a wetting agent, (3) the depth of mercury on which the solution was floated, (4) the temperature of the mercury and of the solution at the time of floating the film, (5) the percent of formaldehyde in the formalin cure, (6) the time of exposure of the film to the atmosphere prior to covering, (7) the amount of water or ethonol used as a coating to the cover, (8) the amount of solution placed on the mercury surface, (9) the volume of air in which the film was cured, (10) the temperature of the air during the curing time, (11) the time of cure, and (12) the area of the mercury surface upon which the film was floated.

The percent solution: This variable was changed from 1/20% to 2% gelatin to water by weight. The strength of solution is not an independent variable but is dependent upon the thickness of film desired and the amount of solution placed on the mercury surface. Over the range of percent gelatin solution used, satisfactory films were produced. It should be noted that a fresh solution is required daily. When the prepared gelatin solution stands for over 24 hours, poorer results are obtained.

The amount of ethanol: The first trials were made using only the gelatin-water solution, but this solution would not spread on the mercury surface. It was found that by adding ethanol to the solution to act as a wetting agent good spreading was obtained. Ethanol was used since it would not leave a residue in the film. It was also found that adding as high a percentage as one part ethanol to two parts solution resulted in too rapid evaporation and an unsatisfactory film. The best films were obtained using one part ethanol to four parts solution by volume.

The depth of mercury upon which the films were floated: This was varied from the minimum possible for mercury to approximately 3/4 inches. The best films were obtained when they were floated on the minimum possible depth of mercury. It is considered that the problems encountered in floating the films on the greater depths of mercury were probably due to the temperature of the mercury rather than the consideration of the depth. However, this problem was not fully investigated.

The temperature of the mercury and the solution: This was a very important variable. It was found that in order to obtain good spreading of the solution over the mercury surface, it was necessary that both the mercury and solution be at approximately the same temperature. In order to reach this condition the mercury was heated by a 100 watt incandescent lamp for approximately one half hour before the film was floated. If the mercury was at too high a temperature or several degrees below that of the solution, unsatisfactory spreading resulted. However, precise measurements of the temperatures of the mercury and solution were not made.

Percent of formaldehyde in formalin cure: This was varied from a 15% solution to a 37% solution. A better quality of films was produced with the 15% solution. The formalin was introduced into the curing atmosphere as soon as the solution had spread evenly on the mercury surface.

The time of exposure to the atmosphere before covering: This was varied from approximately two seconds to 60 seconds. It was found that a minimum exposure was desirable because the film started to set very rapidly on exposure to the atmosphere and the ethanol immediately started to evaporate. The longer exposure caused the formation of imperfections in the film surface. The rapid covering also reduced the possibility of getting lint or dust on the film surface.

The amount of water or ethanol in the air: This was varied by changing the amount used to coat the inside of the cover. This was varied from zero to a very heavy coating of both ethanol and water. It was found that a heavy coating of water was necessary for the production of a good film, presumably through its slowing of evaporation of moisture from the film. The coating of ethanol apparently had little or no effect.

The amount of solution placed on the mercury surface: This was varied from one to 17 drops which was a variation of from 0.05 ml to 0.85 ml of solution. The use of greater amounts of solution resulted in uneven curing which tended to produce a concentration of solution and therefore increased film thickness, at the center. This pulled wrinkles into the film. One drop was not quite sufficient to properly cover the surface. The best films were obtained using two or three drops.

The volume of air over the mercury surface: This was varied from 80 $cm^3$ to 13,000 $cm^3$ or from the volume of a 2 cm deep petri dish to a medium size bell jar. It was found that satisfactory films could be obtained with both 80 $cm^3$ and 300 $cm^3$ volumes, but that unsatisfactory films were formed with an air volume of 600 $cm^3$ and above. Although many of the other variables were changed with the larger volumes of air, no satisfactory films were produced when the air curing volume was above 300 $cm^3$.

The temperature during the curing time: This was varied from that of normal room temperature to that produced by a 100 watt incandescent lamp approximately 25 cm above the mercury surface. It was found that better films were produced when cured at normal room temperature than when the heating lamp was placed over the curing volume. Presumably, the additional heat provided for faster evaporation of the water and a faster cure which resulted in a wrinkled and distorted film surface.

The time of cure: This was varied from 10 hours to one week. Although there was not a great deal of variation noted in the quality of the film, it is considered that a 48 hour cure is necessary for the strength of the film and that a cure of a greater period produces little improvement.

The area of mercury over which the film was floated: This was retained essentially constant at a nine centimeter mercury diameter.

In order to accommodate the optimums of the above variables, the apparatus shown in Figure 7 was designed. Using this apparatus and holding each of the variables at the optimum as outlined above, approx-

imately 90% of the films made, over a range of 300 to 10,000 $A^o$, were successful.

Various means of removing the film from the surface of the mercury were tried. These included: (1) Using a gelatin solution to glue a ring on top of the film surface and lifting it straight up by means of a fine threaded screw device, (2) by filling the petri dish so the meniscus of the mercury was well above the edge of the dish and with the same ring glued to the film, sliding the mercury out from under the ring, (3) by overflowing the mercury onto a piece of plastic and with the film glued to the same ring, sliding the film out over the plastic and attempting to drain the mercury from between the film and the plastic, (4) by placing the ring under the mercury and attempting to lift the film off from underneath, (5) by attempting to hold the film with tweezers and floating the film off over the edge of the petri dish, (6) by using a needle placed under the edge of the film to lift it off, and (7) by placing a piece of plastic flat down on the film, gluing it to the film and sliding it off. None of these methods proved practical because the surface tension of the mercury was so strong that the film adhered to the mercury and was not strong enough to be removed from it.

Two 10,000 $A^o$ thick films were successfully removed from the mercury surface by the insertion of a glass rod of about two millimeters diameter under the edge of the film and gently lifting it from the surface. Pursuing this method further it was found that thinner films of approximately 5,000 $A^o$ could be lifted by the use of two

millimeter diameter glass rods shaped into a ring or a horseshoe. Before starting to lift the film the petri dish was filled with mercury using a hypodermic needle. With the mercury even with the top edge of the petri dish, the horseshoe shaped glass rod was carefully inserted under the film and gently lifted allowing the closed end to clear the mercury surface. The film was then lifted with the plane of the ring as perpendicular to the mercury surface as possible. After some perfection of this method a film of 2,400 $A^o$ was lifted and it is felt that with additional practice, films of 1000 $A^o$ thickness or less could be lifted. The glass lifting apparatus is shown in Figure 8. It is to be noted that an attempt was made to lift a 300 $A^o$ film utilizing a glass rod, but the rod pulled right through the film.

After the film was lifted and mounted on a ring, a normal vacuum evaporation procedure was used in attempting to evaporate an antimony mirror of approximately 40% reflectivity onto the gelatin film. Nine attempts were made to mirror a film, and in each instance the film broke before the coating could be applied. The films broke during the process of evacuation, some almost immediately after the pump was started and others at a later time during the operation. It was considered that the cause of the breakage was water that was retained in the gelatin and which would vaporize rapidly at the low pressures. It was further considered that a second curing period of about three to five weeks in a desiccator would eliminate this problem. Since there was not sufficient time available to test this theory, a commercially obtained film of approximately 30,000 $A^o$ was tried and successfully coated.

Various means were utilized in attempting to glue a film to the cell mosaic using Eastman 910 glue. None of the methods attempted proved feasible. Regardless of how thin a layer of glue was introduced to the cell mosaic, a small amount of glue would roll over the interior edges of the capillary tubes and cause an inclusion of the film into the tube. This of course ruined the optically flat surface and was unsatisfactory. It was also attempted to place the gelatin film over the optically flat surface and allow it to dry. In the laboratory model, none of these attempts proved satisfactory and the second cell mosaic was used to hold the film in place.

The system, less chopper and schlieren system, is fitted into a compact holder, the design of which is included as Figure 9.

8. The schlieren viewing system

In order to detect the bulging of the film when infrared radiation causes pressure within the cell to be increased, an optical system is required. For the laboratory work a Foucault Knife Edge Attachment used with a precision optical bench was used as the optical system. This was used in conjunction with a precision lens to operate as a reflecting schlieren system. The Foucault Knife Edge Attachment utilized was Model L-360-NMK used with Optical Bench Microscope L-360-NM manufactured by the Gaertner Scientific Corp. of Chicago. When the film is flat the reflected light is focused on the knife edge and the field of view is dark. When a bulge occurs the reflected light is distorted and enters the telescope system. The increased distortion is viewed as an increase in intensity of light.

The entire laboratory unit is shown in Figure 10.

9. Unit cell response measuring device

Theory indicates that the optimum length to radius ratio of a pneumatic thermal detecting cell is 1.2. It was desired to experimentally verify this theoretical calculation. In view of the fact that we planned to utilize carbon black as the radiation absorber in the cells of the mosaic, it was desired to determine the effect of varying the amount of carbon black placed in the cells. In order to measure these parameters, it was decided to measure the temperature in various sized tubes by means of a thermocouple when a specific amount of radiation energy was introduced into the tube. The use of a thermocouple was decided upon because of the following factors: (1) We were unable to find a satisfactory means of measuring a pressure change when such small tubes and such small changes in pressure were involved. (2) The temperature increase would be proportional to pressure increase. (3) It was desired to make the measurements at as nearly a constant volume condition as possible. (4) It was desired to minimize the error caused by the introduction of a measuring device into the small volume tubes, and a thermocouple junction was as small a measuring device as we could envision.

A black body provided the radiation which passed through a small hole in an insulating shield and through an IRTRAN-2 window into the tube being measured. The tube under consideration was placed against the IRTRAN-2 window, centered over the hole through which the radiation passed, and a plastic backup plate was screwed tightly against it. One junction of the thermocouple was inserted through the plastic backup plate so that when the tube was in position against the IRTRAN-2

window the thermocouple junction was in place within the tube. This device was then placed in an insulated box, aluminum lined in order to reduce the temperature gradients and to provide electrical shielding. The black body radiator was placed a specific distance away from the IRTRAN-2 window for each measurement and a quick action door was opened to allow the radiation to enter the tube for a specific amount of time. The voltage produced by the difference in temperature between the thermocouple junction in the tube and the junction at the ambient temperature of the constant temperature box was measured by a microvoltmeter which in turn was connected to a recording device. A constant ambient temperature within the box was maintained by means of a heating or cooling coil. A diagram of the apparatus is included as Figure 11.

10. The thermocouple

The most important part of the above apparatus was the thermocouple which measured the change in temperature within the tube. A thermocouple was constructed using one mil bismuth wire and 1.3 mil 95% bismuth 5% tin wire. In using such small wires a handling technique had to be developed so that the wire was not being constantly broken. A large magnifying glass was used on a mount, and needles were used to handle the wire. The joints were soldered using woods metal as the solder and stannous chloride as the flux. Zinc chloride was tried as a flux but proved to be unsatisfactory. Some experimentation was required to find a successful soldering technique which was as follows: (1) Using the needles the wires were positioned on a microscope slide and contact at the junction was checked. (2) Less than one drop of flux was placed at the junction. (3) Most of the flux was absorbed with the corner of a tissue. (4) A small slice of woods metal approximately 5 mils thick and 10 mils square was placed on the junction with the convex side downward so that it was in good contact with the junction. (5) The soldering iron was held resting on the glass so that both glass and wire were heated, and then the iron was tilted so that it was approximately two millimeters above the woods metal. The radient heat and the heated glass were sufficient to melt the solder and form a good junction. (6) The junction was rinsed with distilled water.

The junction which was to be used within the tube was made in this manner. After completion the two wires were placed within a capillary

tube. The capillary tube was fastened to a microscope slide with beeswax to hold it steady, and one end of the tube protruded over the edge of the slide approximately 1/8 inch. The slide on which the wires had been placed was raised so that it was even with the bottom of the tube and the wires pushed into the tube with the needles. The length of the tube corresponded to the thickness of the backup plate. The wires were placed in the tube so that the junction was completely exposed, the two wires were not in contact anywhere in the tube, and the wires were exposed approximately $\frac{1}{2}$ inch on the other end. Epoxy resin was used to seal the capillary tube and insulate the wires from each other. The epoxy was introduced into the capillary tube by using a small drop on the end of a needle and touching it to the end of the tube. Capillary action sucked the epoxy up into the tube and additional drops were added until the tube was filled. The epoxy was heated to reduce its viscosity, and during the operation the tube was heated by touching it with a hot glass rod.

The capillary tube was then placed in a small hole in the plastic backup plate and glued into position. The result was one junction of the thermocouple protruding slightly from the front surface of the plastic backup plate. A microscope slide was placed on the back of the backup plate and after carefully bending the wire down, the second junction was made in a manner similar to that used for the first. The wires were then soldered to copper disks on the back of the plastic plate which in turn were connected to leads to the microvoltmeter. The thermocouple constructed in this manner gave readings on the microvoltmeter when exposed to different temperatures of water, but did not

give readings for changes in air temperature at the exposed thermocouple junction. It was considered that this junction was too near the plastic backup plate and that the temperature of the plate kept the junction at a more or less constant temperature. It was also considered that the junction had too small an area exposed to the warmer air and that the heat was conducted away from this junction as fast as it was absorbed.

A second thermocouple was fabricated using three mil bismuth and bismuth-tin wire. In lieu of the small junction previously utilized for temperature measurement within the tube it was decided to use a folded gold foil strip, welding one of the wires to each end. The gold foil strip used was approximately 5 mils thick, one millimeter wide and one centimeter in length. The equipment used in the welding operation is indicated in Figure 12. A three volt battery supply was connected through a telegraph key switch to two needle probes. The wire was held in contact with the gold foil using the needle probes placed very near the junction, and the telegraph switch was tapped intermittently with short, sharp periods of contact. While the key was being tapped the needles were changed slightly in position until a spark occurred between the wire and the gold foil, welding the wire to the foil. After the two wires were welded to the foil, the thermocouple was placed in the capillary tube by the method used on the previous thermocouple.

After securing the capillary mount into the plastic backup plate, the folded gold foil protruded approximately three millimeters from the front surface of the backup plate. The junction of the bismuth and

bismuth-tin wire behind the backup plate was accomplished by welding, using the needle probes in the same method used for the wire and gold foil. The bismuth wires were then soldered to the copper disks which were mounted to the back of the plastic plate as was done with the thermocouple discussed above. It was found that with the use of the larger heat absorbing area that changes in air temperature were detected with this thermocouple.

In the month and one half required to produce the working thermocouple, many attempts were made and much experimentation was done on various operations to evolve the procedures just described.

11. The conical black body

In order to provide a large source for testing the final apparatus, a large water filled conical black body was constructed similar to one developed for the infrared program of Project Michigan. /11/ The inner surface of the black body was made of sheet metal rolled into the shape of a truncated cone with an approximate angle of $22.5^{\circ}$ and a base diameter of 11.92 inches. The apex of the cone was machined from a piece of brass and soldered to the small end of the truncated cone. The result was a large continuous cone from apex to base. The unit was fitted with a conically shaped jacket with a spacing between the two cones of approximately $2\frac{1}{2}$ inches. At the point where the jacket reached a diameter of approximately four inches, a cylinder of four inch diameter and eight inches long was attached. In this cylinder was placed a 500 watt heater and an impeller blade coupled through a water tight fitting to a motor mounted at the end of the cylinder. In addition, baffles were placed in the cylinder to smooth out the flow from the impeller blades. There were four hose fittings placed at the back of the cylinder. The impeller forced the water through the jacket and the water was returned to the point of origin through the hoses. The water temperature was controlled by a Fenwal Thermoswitch which has a range from $100^{\circ}$ to $400^{\circ}$ F.

Similar conical black bodies used in Project Michigan were found to have a temperature variation of about $1.5^{\circ}$ C from base to apex for a water temperature of $60^{\circ}$ C. The emissivity calculated for the cones of similar dimensions used in Project Michigan was .996. A diagram of the conical black body is included as Figure 13, and a picture is shown as Figure 14.

12. Procedures for measuring response of unit cell

Since theory indicates that there is an optimum length to radius ratio of 1.2, it was considered desirable to verify this experimentally. It was also desired to determine the shape of the cell response curve with time, the shape of the curve of response versus length to radius ratio, and the effect of varying the amount of carbon black which was placed in the cells.

The equipment used to accomplish this was discussed in section 9. In conjunction with the unit cell response measuring device discussed in that section, a small conical shaped black body, Infrared Radiation Reference Source, Model RS-1B/TC-1B manufactured by Barnes Engineering Company was used as the radiation source. A Hewlett Packard DC microvolt-ammeter, Model 425A, was used to measure the output of the thermocouple. Connected to the output of the microvolt-ammeter was a Moseley Autograf x-y recorder, Model 2S, which produced a recording of the thermocouple output.

As indicated in section 9, it was desired first to measure the change in temperature within various sized tubes when a specific amount of infrared radiation was introduced into the tube volume, while maintaining a constant ambient temperature and constant tube volume. The constant conditions utilized for each tube were as follows: (1) The amount of infrared radiation introduced was held constant by: (a) Maintaining the radiating source at a temperature of 200° C, (b) maintaining a constant time of exposure by operation of the quick action shutter allowing the radiation to enter the tube for a period of ten seconds, (c) the area of radiation exposure was held to a constant by maintaining a four

millimeter diameter opening in the insulated box as the only means by which the radiant energy could enter the tube being tested, and (d) maintaining a constant distance between the black body radiator and the front of the tube being tested. (2) A constant ambient temperature of $22^{\circ}$ C was maintained in the box by circulating hot or cold water through the copper coil in the bottom of the box as required. (3) By coating only the sides of the tubes with carbon black, the amount of carbon black was maintained as nearly constant as possible. (4) Since the backup plate and the IRTRAN-2 window formed the two ends of the tube, and the tube fit snugly against these surfaces, each test was made at constant volume.

The tube diameters considered were four, five, six, eight, and ten millimeters inside diameter. The lengths in each tube size were varied from four to 23 millimeters. A total of six exposures of ten seconds duration were made on each tube investigated. When investigating the response for the change in amount of carbon black, a tube of 6 mm ID and 12 mm length was used. The carbon black was varied from .0110 grams with the sides coated only to .0172 grams.

Certain physical differences exist between the unit cells which were tested and the cells in an actual cell mosaic. (1) The backup plate of the test tubes was made of thick plastic which will absorb some radiation. In the actual tubes the back surface of the cells is a thin film with a shiny antimony coating which will transmit a small amount of infrared radiation and will reflect and absorb some, but since it is so thin it will conduct very little of the energy away.

(2) A ten second exposure to radiation was required to get a measureable response on the tubes tested, where a 1/20 second exposure was planned for the actual detector. (3) The tube sizes used for measuring purposes were larger than the actual cell. It was attempted, by using various sized tubes, to gain an indication of a trend toward smaller tubes, since actual measurements in the small tubes could not be made. (4) The measuring device, the thermocouple, probably absorbed some direct radiation and therefore probably did not indicate actually the correct air temperature change within the tube.

For each diameter tube investigated it was found that, in the range of length to radius ratio tested, the response increased with a decrease in the l/r ratio. A plot of response versus l/r ratio for all of the tube diameters tested is shown on the graph of Figure 15. Also shown on this graph is the shape of the theoretical response curve. In general the results of the experiment followed what was expected, an increasing response with a decreasing l/r ratio. When the l/r ratio approached one, the tubes being investigated were approximately four millimeters in length and the diameters were eight and ten millimeters. In view of the fact that the area for entry of infrared radiation was considerably smaller than the tube diameter being investigated, these points cannot be considered with great reliability. With the thermocouple protruding from the face of the backup plate a distance of three millimeters, it was not possible to obtain sufficient data in the region of an l/r ratio equal to one to indicate an optimum value of l/r.

The temperature response of the cells, as plotted by the x-y recorder, showed the exponential rise that is predicted by theory.

This is shown along with the increase in response with decreasing length to radius ratio by the typical response curves for four lengths of four millimeter ID tubing in Figure 16.

In investigating the change of response versus the amount of carbon black added to a unit cell, it was found that starting with the sides coated with 0.0110 gram and adding carbon black in a very loose manner within the tube, up to 0.0172 gram produced no detectable difference in response characteristics. It is considered that the one test made is not sufficient to draw specific conclusions in this regard, but over the range of carbon black utilized, it would appear that the amount of carbon black is not a critical factor.

In view of the inconclusive results obtained by the use of a thermocouple and a solid backup plate, it is considered that further investigations of this type should be conducted using some pressure measuring device such as a modification of the Hayes cell. /1/ Such a device would more nearly duplicate the actual cell of the cell mosaic and would measure the pressure in lieu of the temperature. It is also considered that other absorbing materials should be investigated, such as ground glass, carbonized fluff, gold black, or antimony black.

## 13. Conclusions and recommendations

A laboratory model of the pneumatic mosaic infrared detector has been developed. The major items included were the development of procedures for producing the 447 unit cell mosaic and the development of procedures for producing consistently good thin gelatin films of thickness between 1,000 $A^o$ and 5,000 $A^o$ and diameter of over two inches.

The response of the unit pneumatic cell was investigated and the results were as predicted by theory; that is, the response increased with decreasing length to radius ratio. The predicted optimum of response at $l/r = 1.2$ could not be checked with the apparatus used.

The final operations necessary to complete the laboratory model were being completed while this report was being written. However, lack of time and a few minor mechanical difficulties prevented the final testing of the model in time for inclusion of data on the responsiveness and sensitivity.

It is considered that using the procedures developed, a pneumatic mosaic infrared detector can be produced with sufficient sensitivity, simplicity and ruggedness for field use of combat troops.

In line with this it is recommended that: (1) Further investigation of the unit cell and absorber materials be conducted to develop the maximum sensitivity, (2) investigation of the porosity of antimony coated thin gelatin films be made to measure the requirement for the provision of additional bleeding, and (3) investigation be conducted into the possibility of developing a rugged reflecting schlieren system.

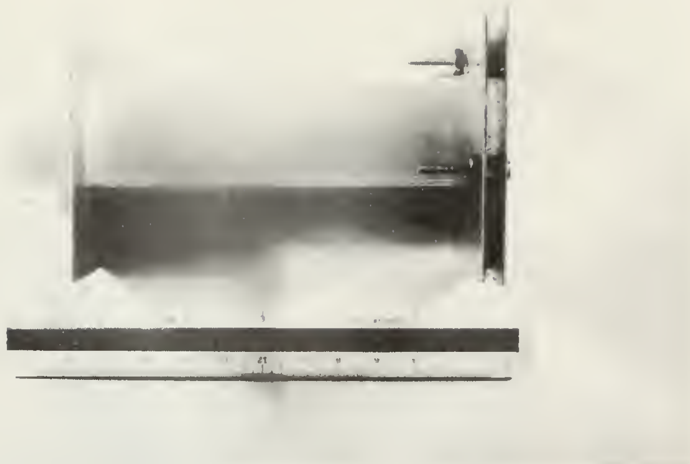

Figure 2

Formation of the Hexagon Tube Bundle

Figure 3

Hexagon Tube Bundle Completed

Figure 4   Circular Tube Bundle Completed

Solvents

| Filler Material | $H_2 NO_3$ (Conc.) | $H_2 SO_4$ (Conc.) | HCl (Conc.) | HAc (Conc.) | Carbon Tet Eth-anol | Ethanol | Turpen-tine | Comments |
|---|---|---|---|---|---|---|---|---|
| Plaster of Paris | No | No | No | No | No | No | No | Not Soluble |
| Beeswax and Resin | - | - | No | - | Good | - | Very Slow | - |
| Parawax | - | - | - | - | - | - | - | Too soft for grinding |
| 1 to 1 Plaster of Paris and Ca $CO_3$ | No | No | Very Slight | No | - | - | - | - |
| 1 to 2 P of P and $CaCO_3$ | No | No | Fair | No | - | - | - | Too soft |
| "Water Stop" | - | Slow | No | No | - | - | - | Too soft |
| Wood Putty | No | Good | No | No | - | - | - | - |
| Spackle Compound | No | Good | Good | No | - | - | - | Too soft |
| Woods Metal | Good | - | Good | - | - | - | - | Leaves hard residue |
| Canadian Balsam | - | - | - | - | - | Very Good | - | - |
| Pure Resin | - | - | - | - | - | - | Very Good | (Pure Resin - Tur-pentine combination used) |
| Armstrong Epoxy "C" | Yes | Yes | Causes Swelling | - | Softens | Softens | No | |

Fig. 5

Table of Filling Agents and Solvents

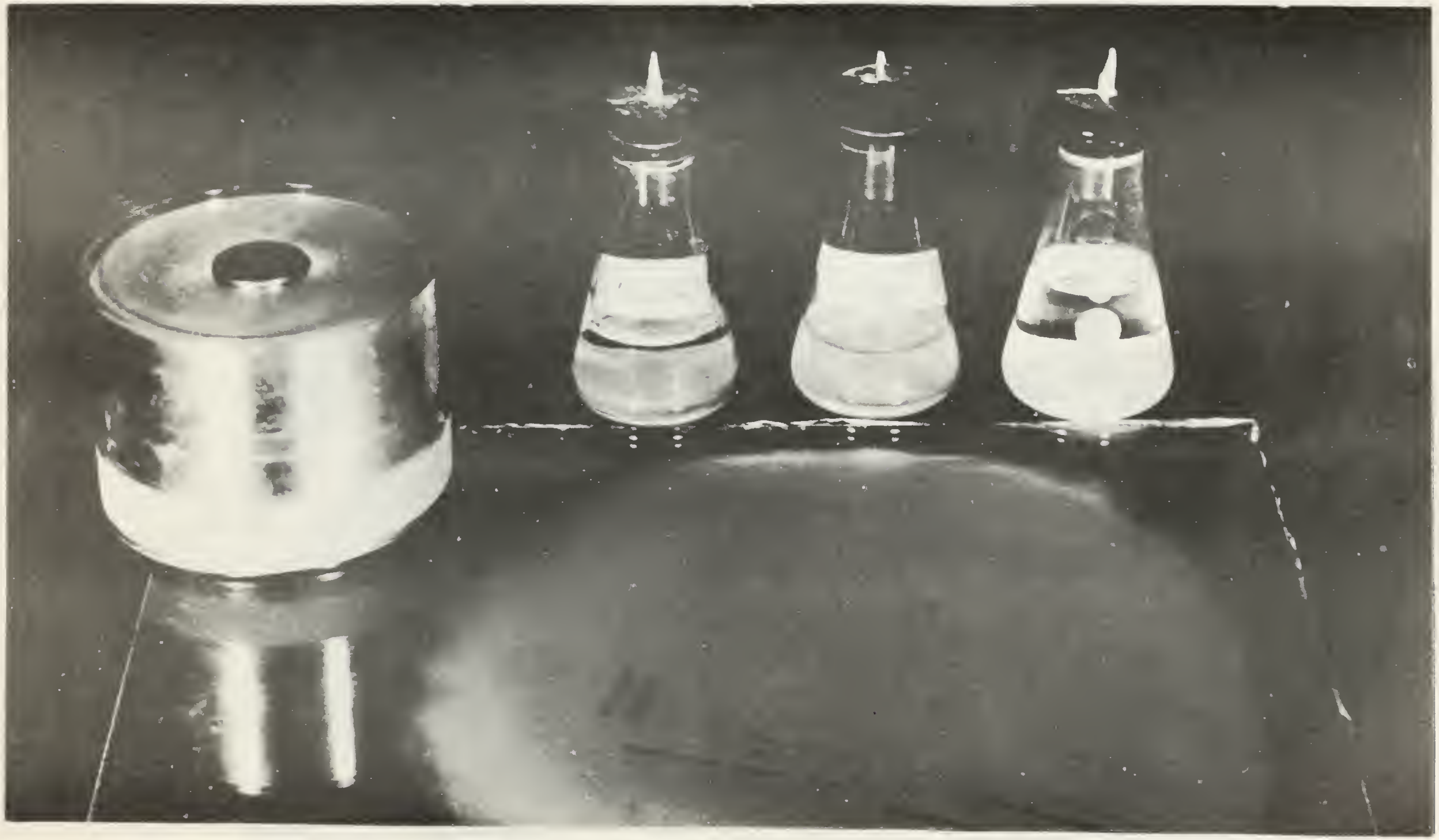

Figure 6 Grinding Cylinder

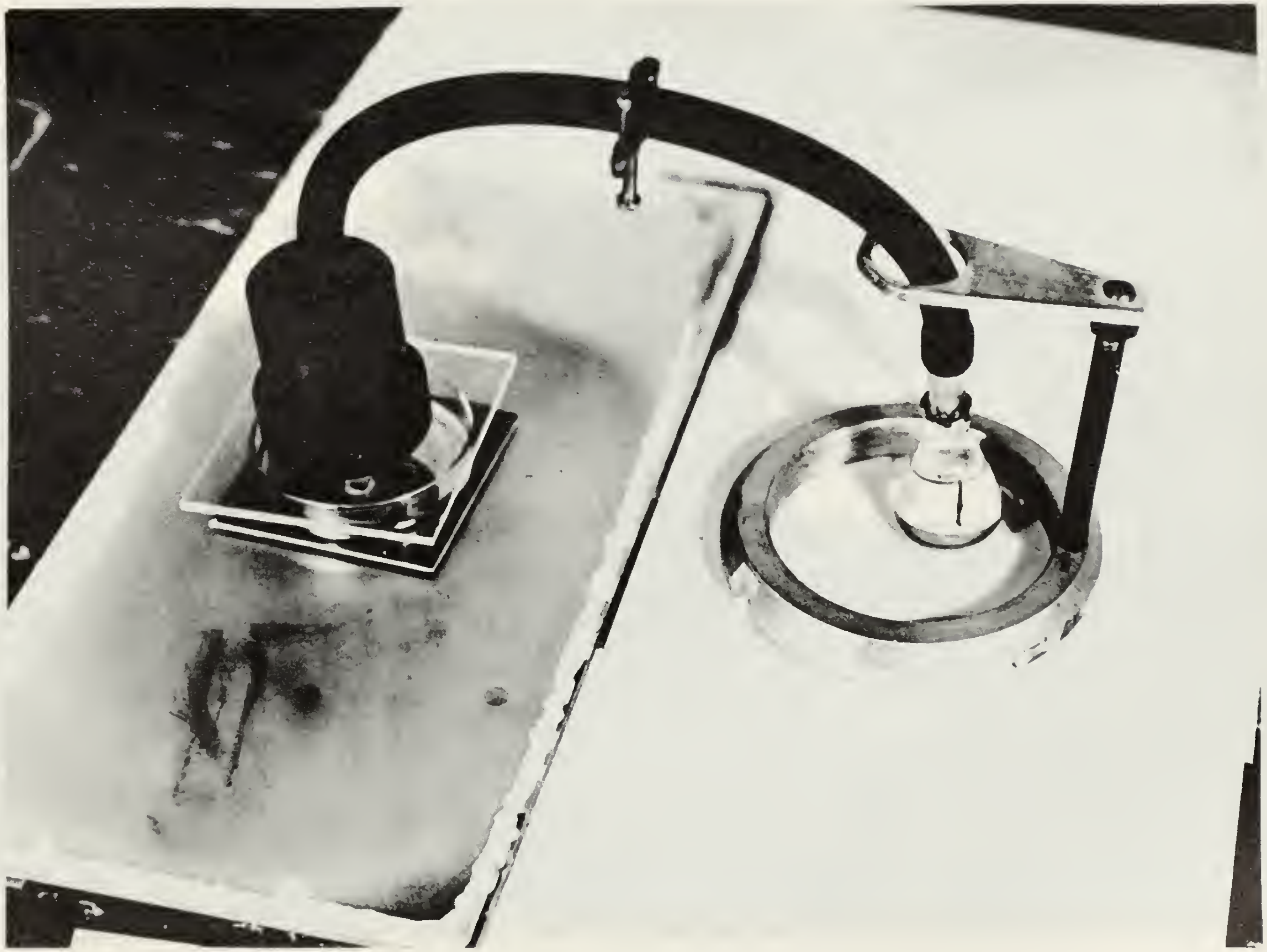

Figure 7 Film Curing Apparatus

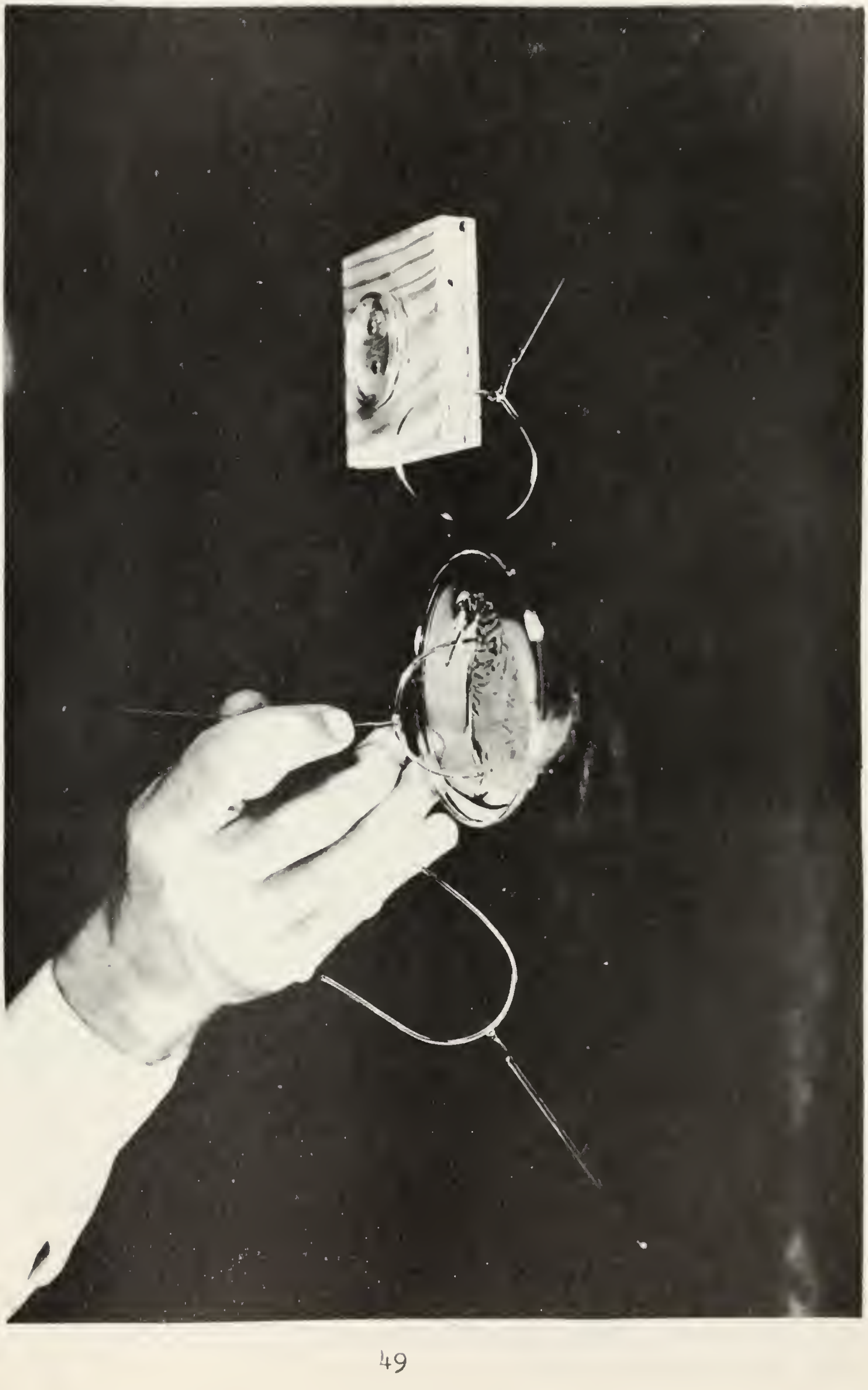

Figure 8 Film Lifting Devices

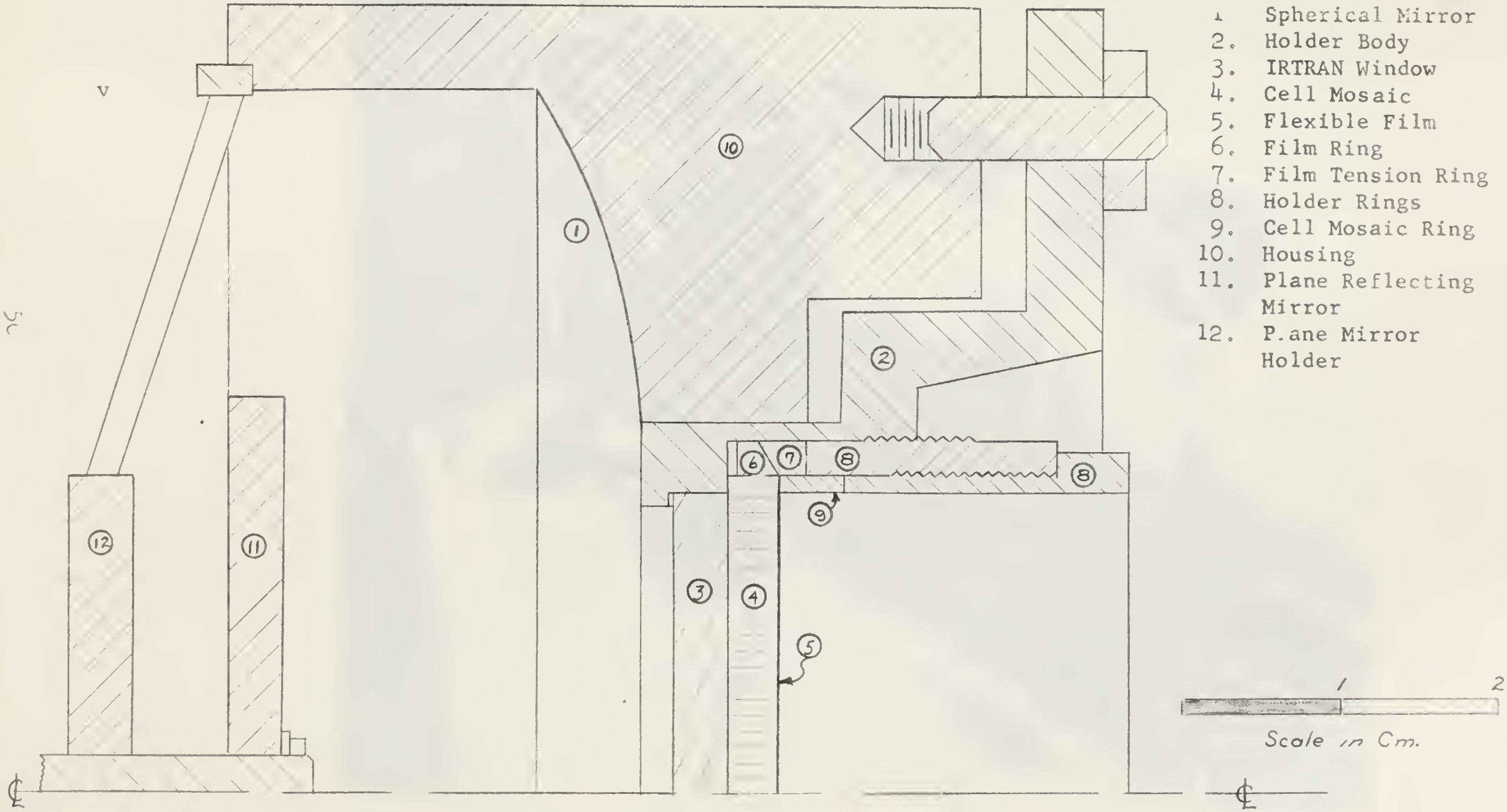


Figure 9

Design of Laboratory Model, Less Schlieren and Chopper System

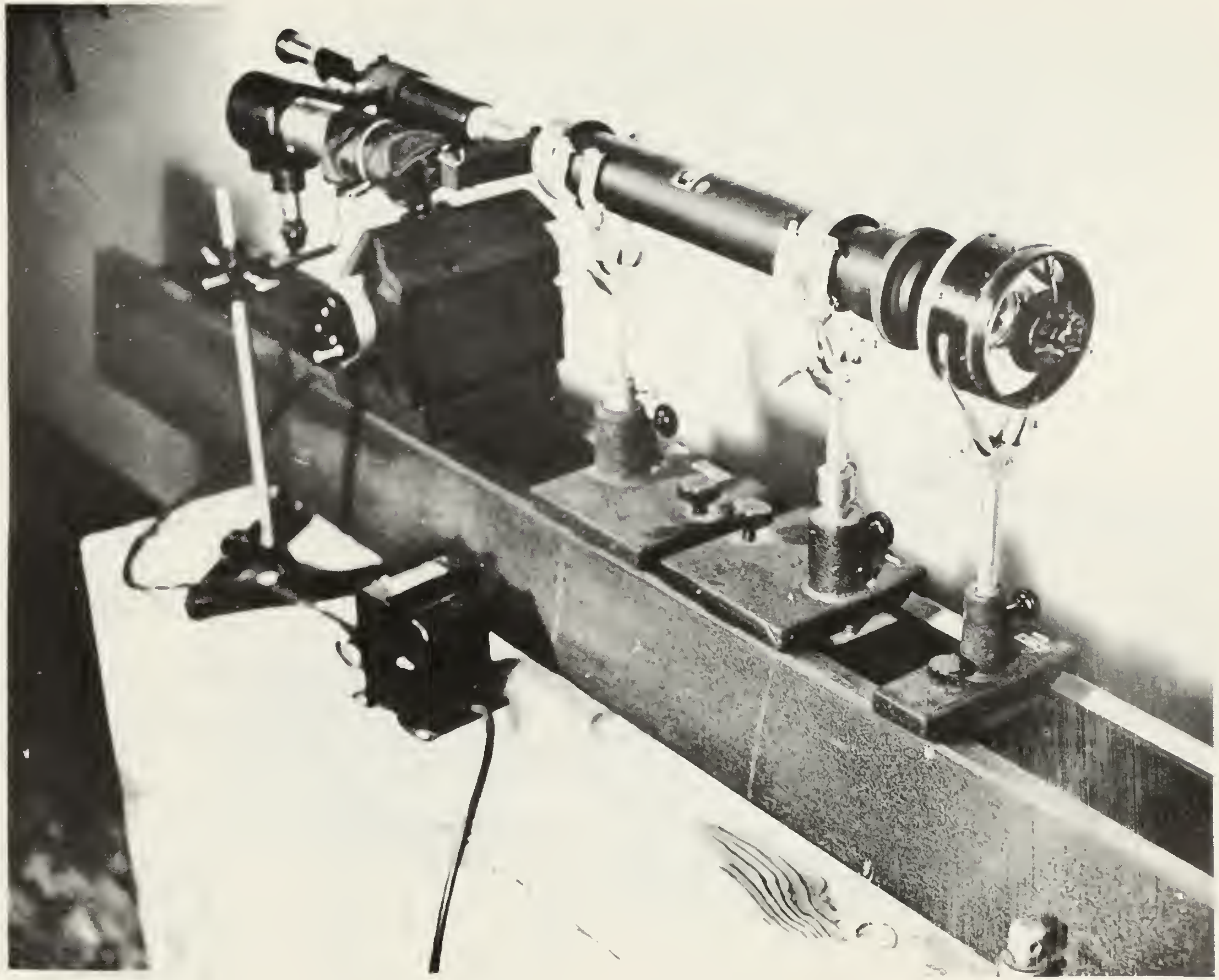

Figure 10 Entire Laboratory Instrument

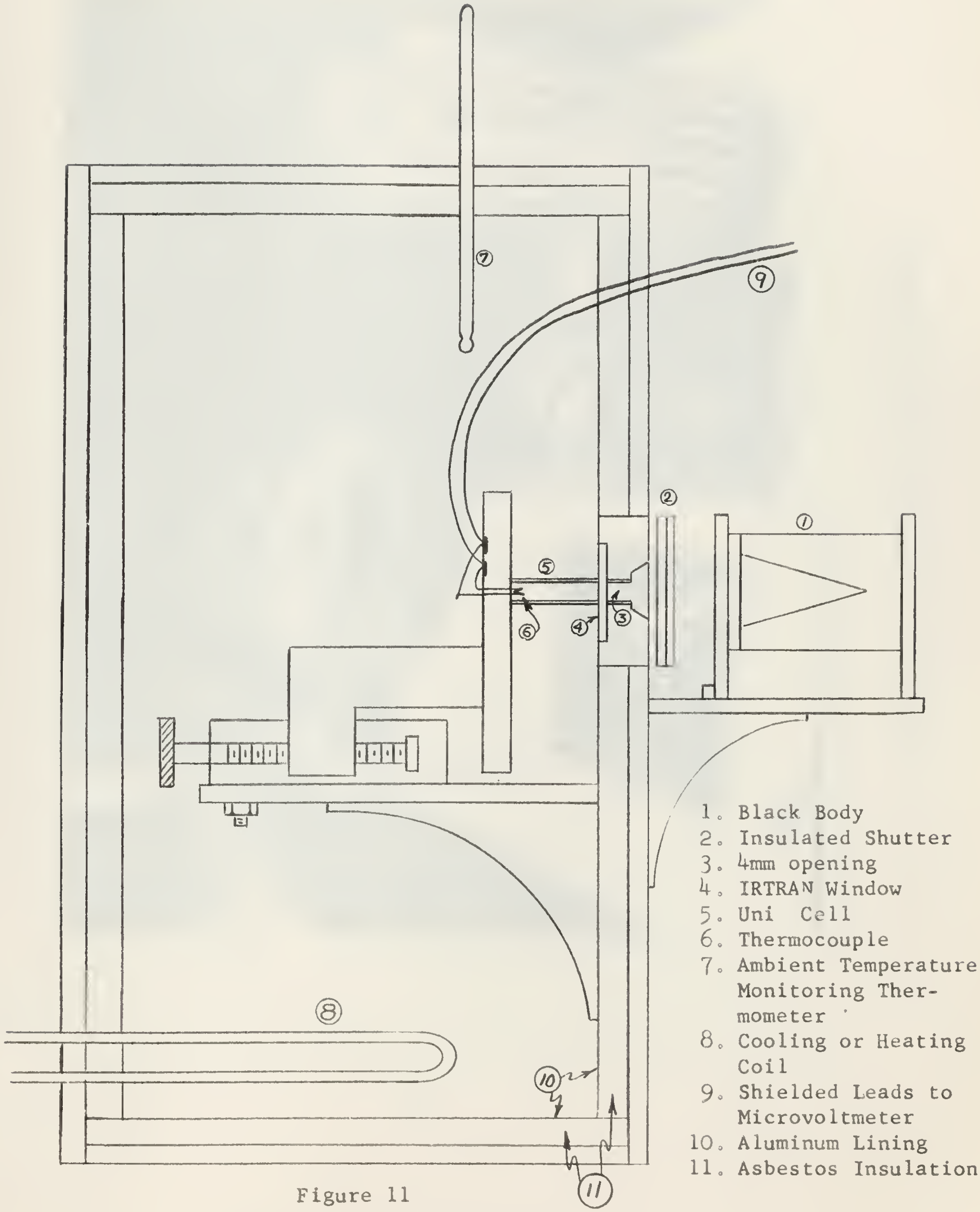


Figure 11

Unit Cell Measuring Device

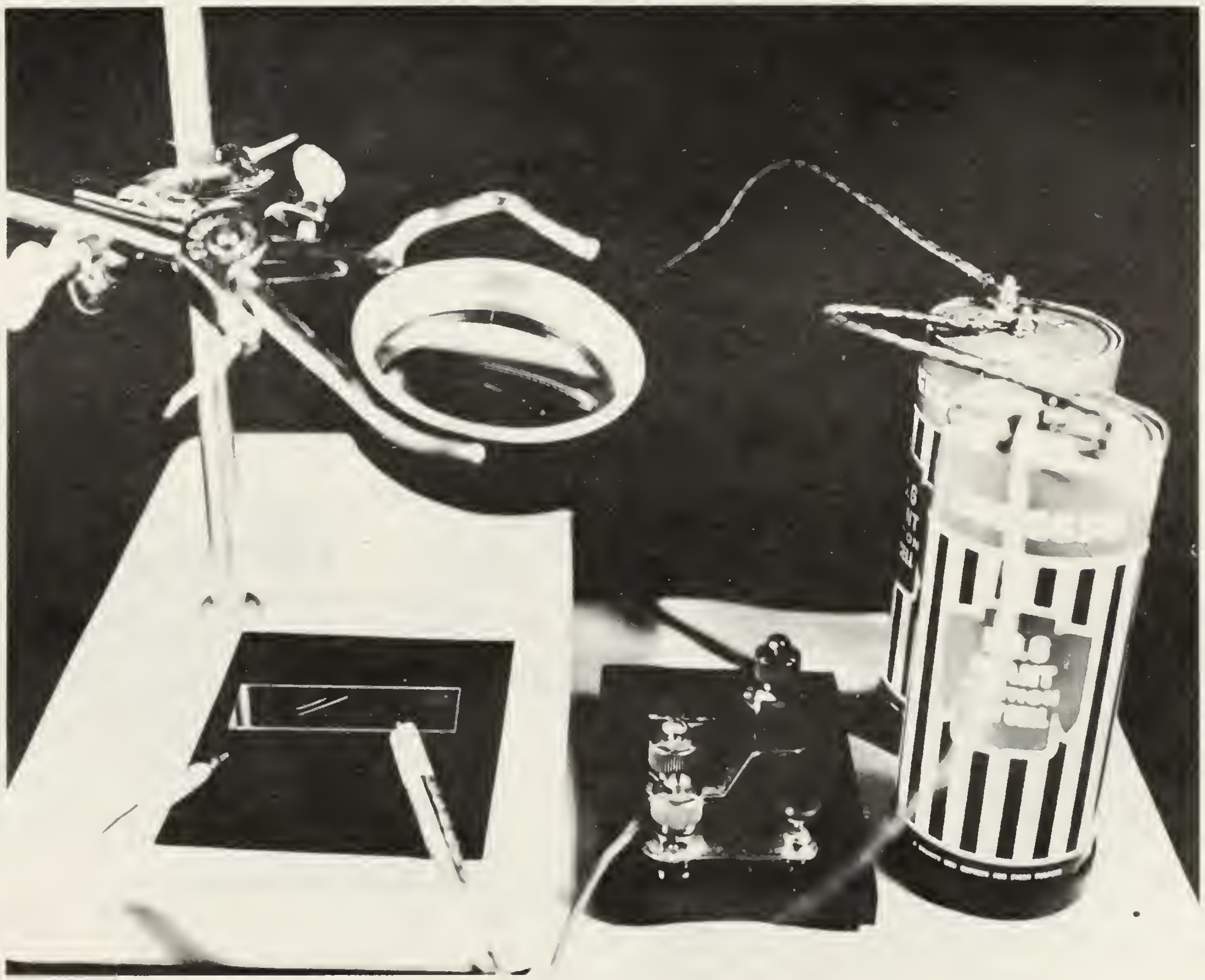

Figure 12 Thermocouple Welding Equipment

1. Inner Radiating Cone
2. Water Filled Jacket
3. Thermostatic Switch
4. Water Return Line
5. Electric Heater Coil
6. Electric Motor and Impeller

Note: Arrows show direction of water flow

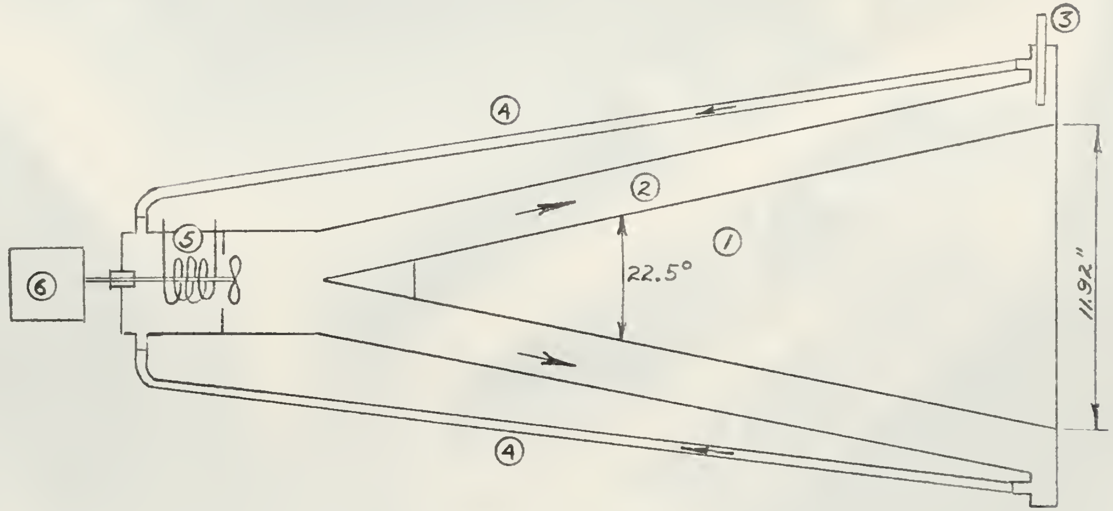


Figure 13

Diagram of Black Body Radiator

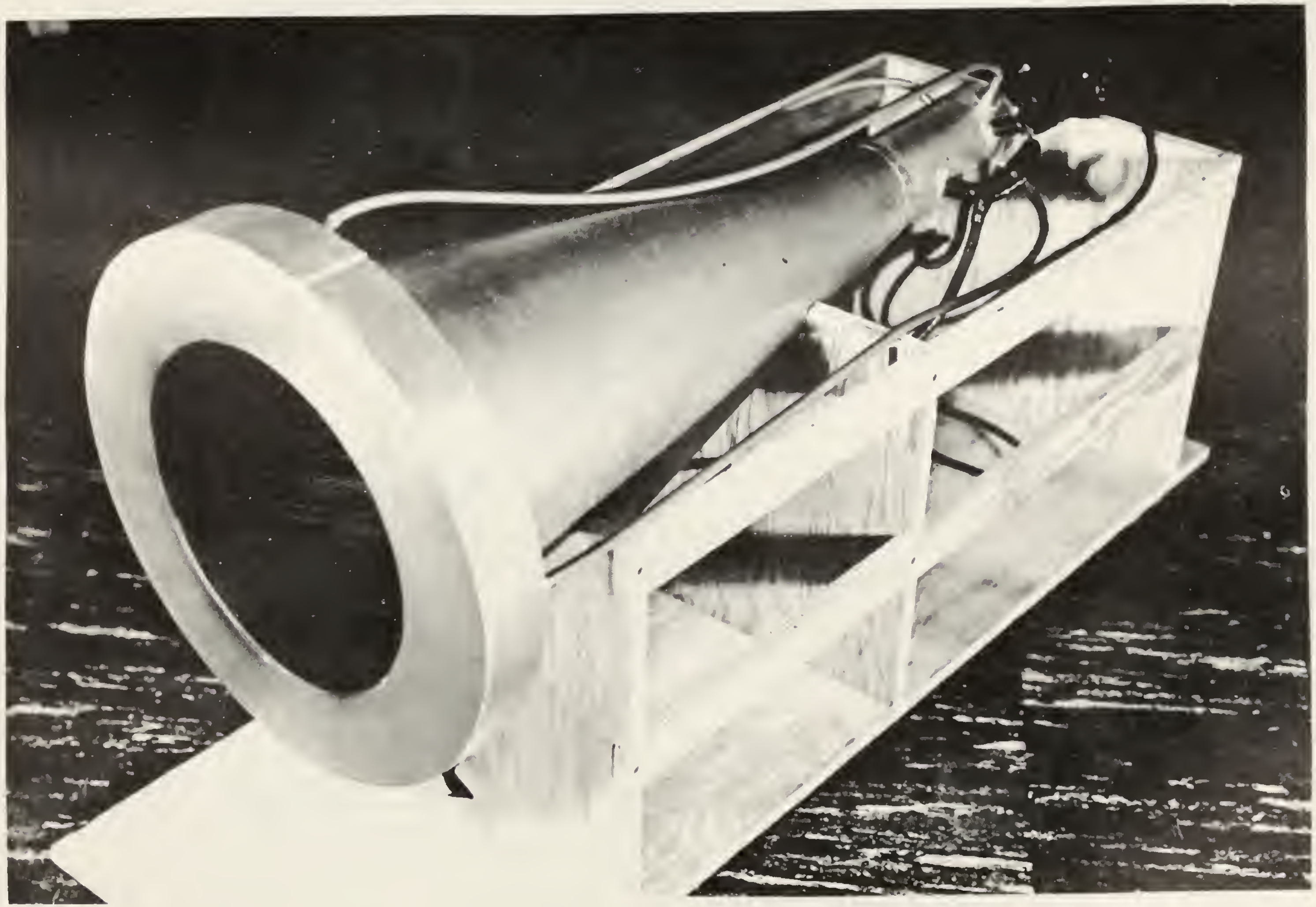

Figure 14 Conical Black Body Radiator

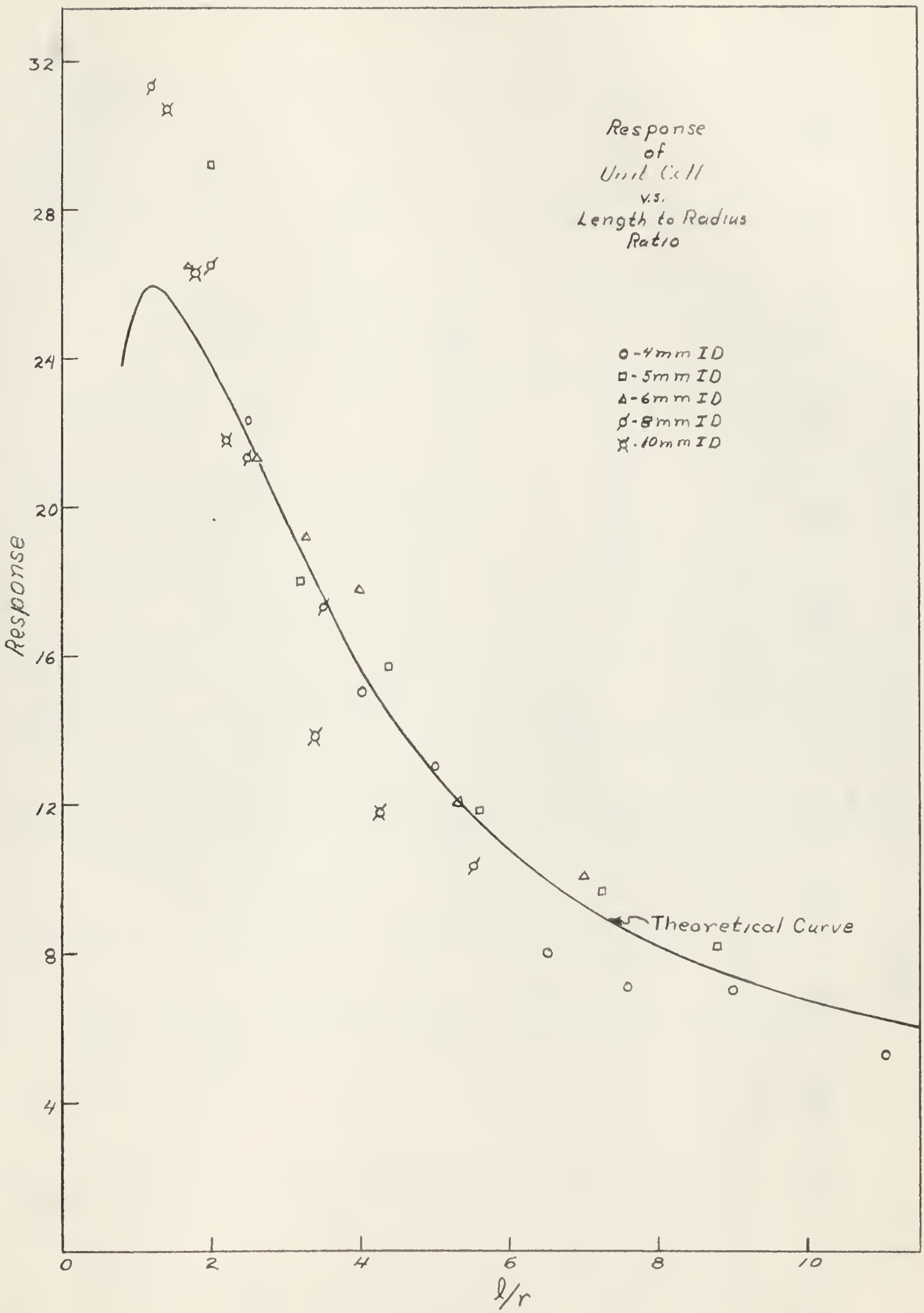


Figure 15

Plot of l/r Ratio vs Response for Unit Cell

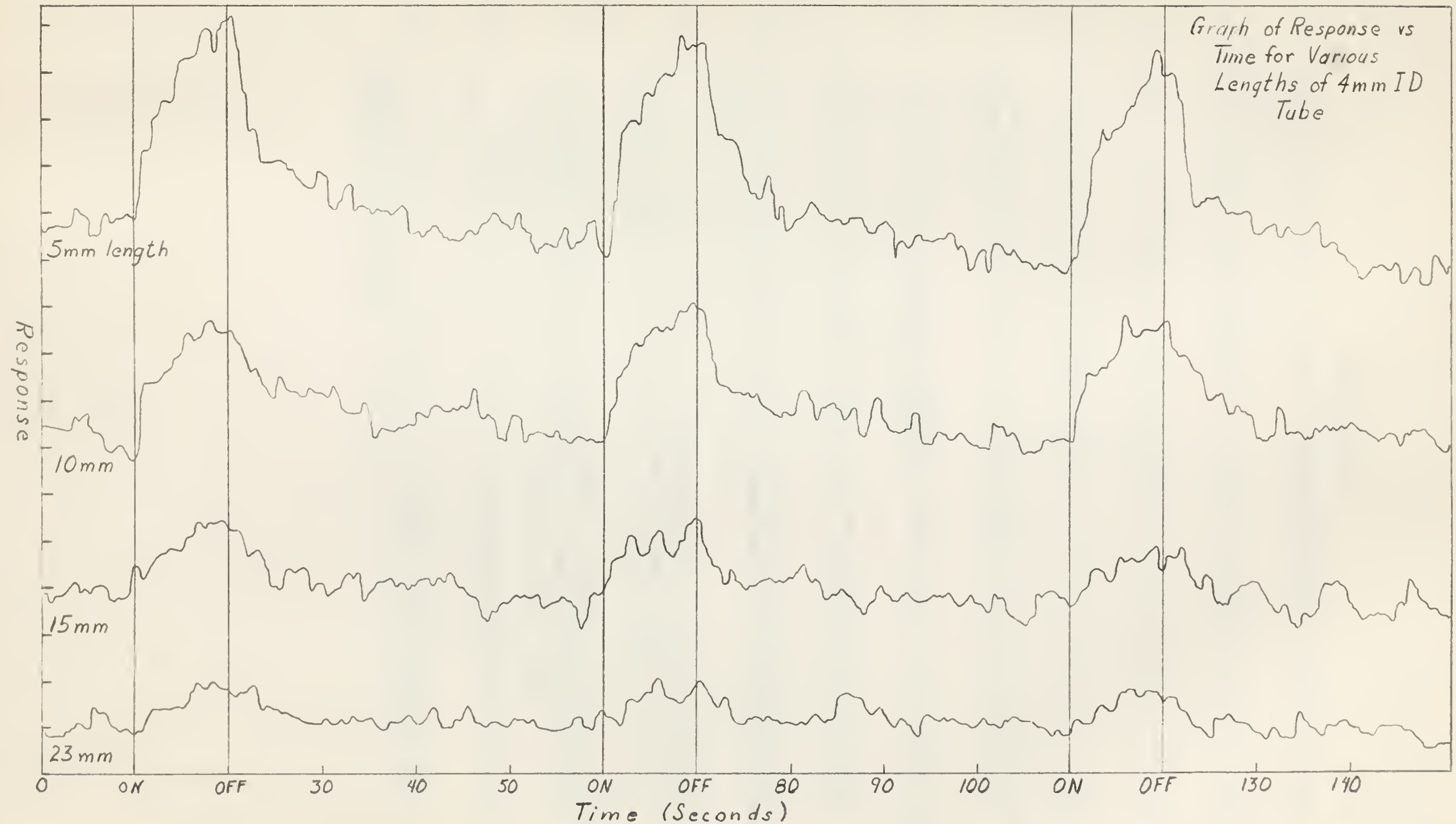


Figure 16 Typical Response Curves for Unit Cell

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